MAPS Technical Overview

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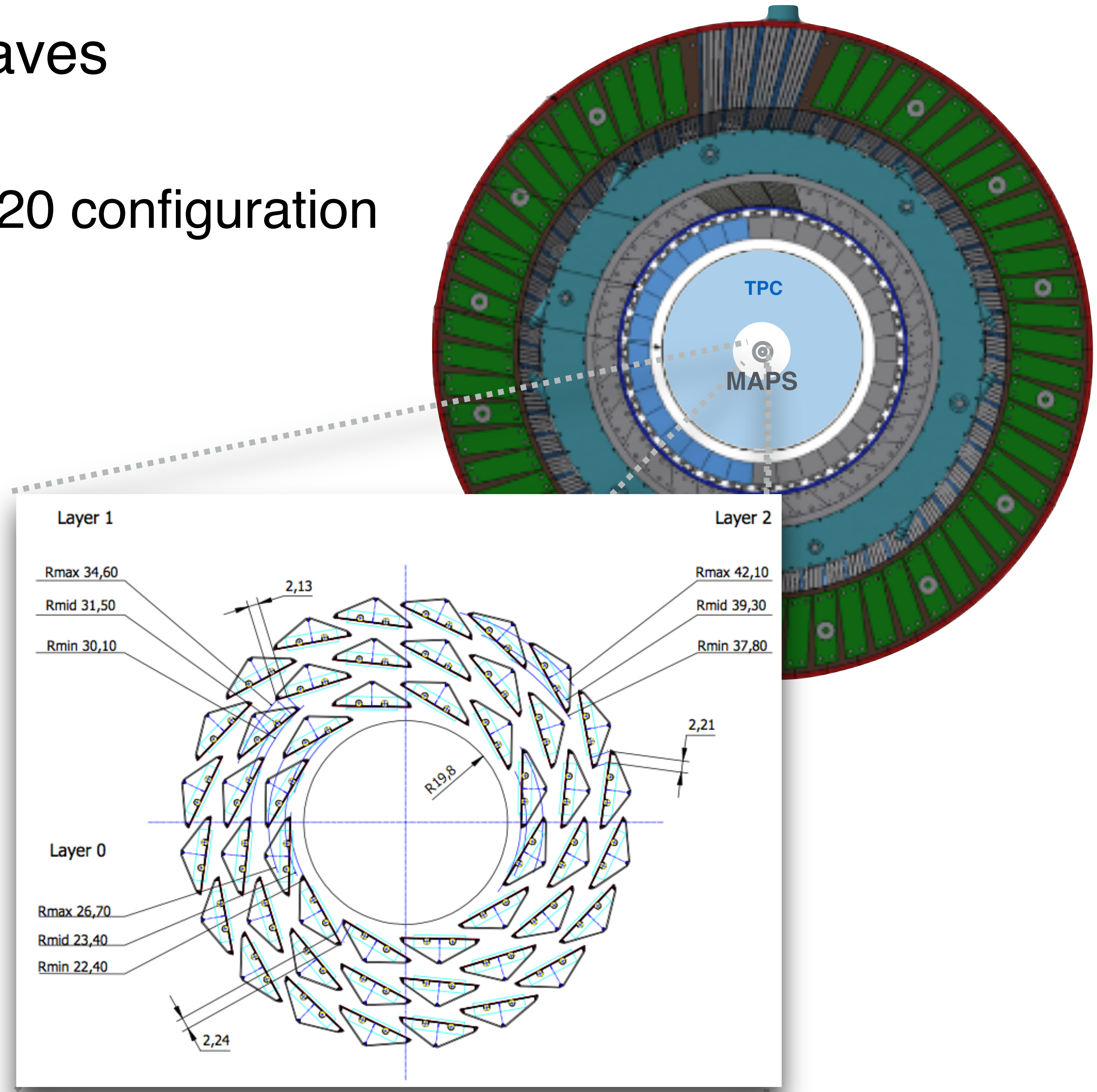
MAPS Performance Specifications

- **Inner Silicon tracking driven by heavy flavor jet performance**
- Track acceptance: $-1.1<\eta<+1.1$ and $0<\phi<2\pi$
- Minimum vertex acceptance: -10 cm < z_{vtx} < +10 cm
- Meet or Exceed a 30% b-jet efficiency at 30% b-jet purity
  - defined by the CMS of b-jet figure-of-merit
- Minimum track efficiency: >95% of all charged particles
- Minimum DCA_{XY} resolution: < 70 microns
- Resolve multiple collisions vertexes at large collider luminosities
- Maintain track momentum resolution:
  - Upsilon mass: dp/p <1.2% for $4 < p_T < 10$ GeV/c
  - Jet Fragmentation: dp/p < (0.2% x p) for $p_T < 40$ GeV/c
- Maintain small rate of tracking ambiguities: *fake tracks*

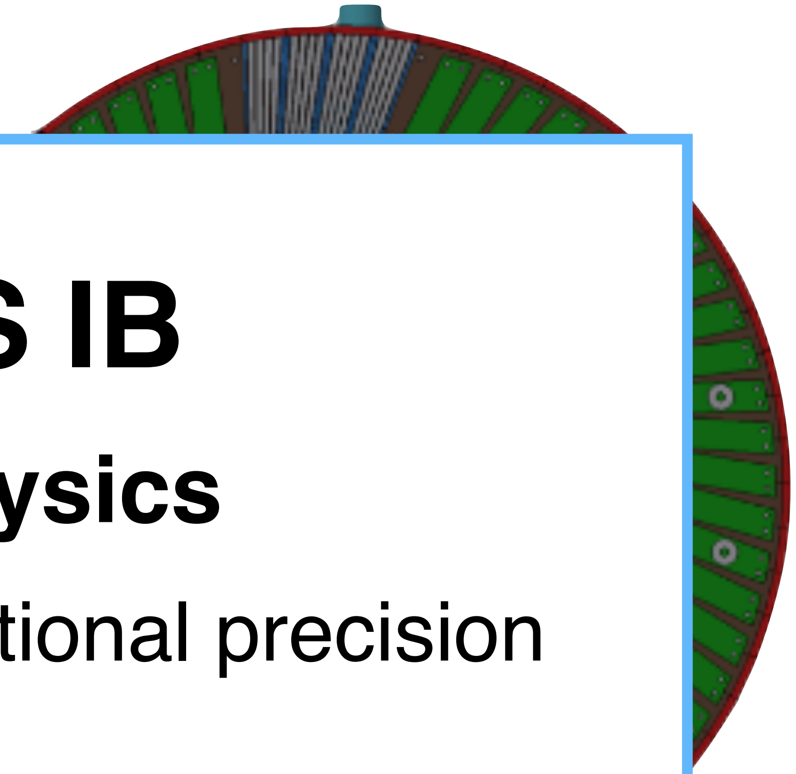
sPHENIX MAPS Description

- ALICE ITS Inner Barrel Staves
  - near-clone of ALICE IB
  - 3-layers in a similar 12/16/20 configuration
  - each stave has 9 sensors
  - each stave ~0.3% X_0
- ALPIDE Sensors
  - 28 x 28 um pitch
  - 99.9% efficiency
  - 2-4 usec integration time
  - on-pixel digitization
- sPHENIX Readout
  - Modified FEM-based on ALICE Readout Unit



sPHENIX MAPS Description

- ALICE ITS Inner Barrel Staves

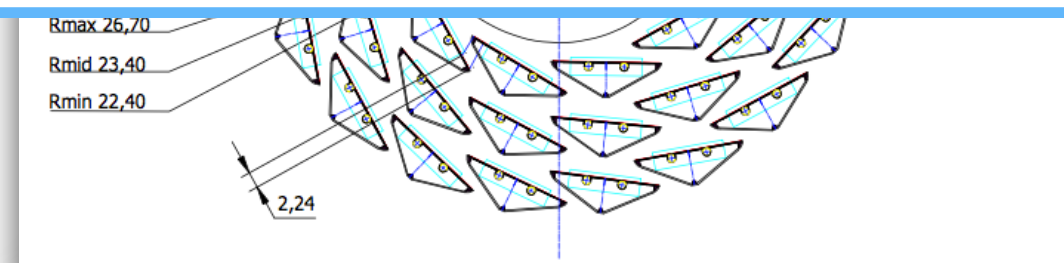


Benefits of ALICE ITS IB

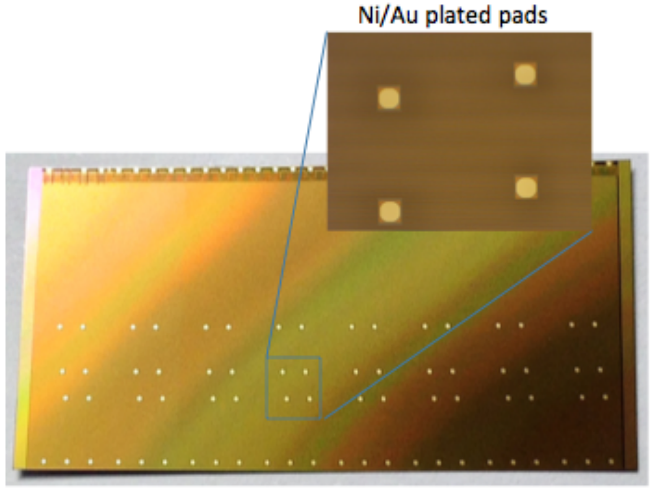
Minimize Risk, Maximize Physics

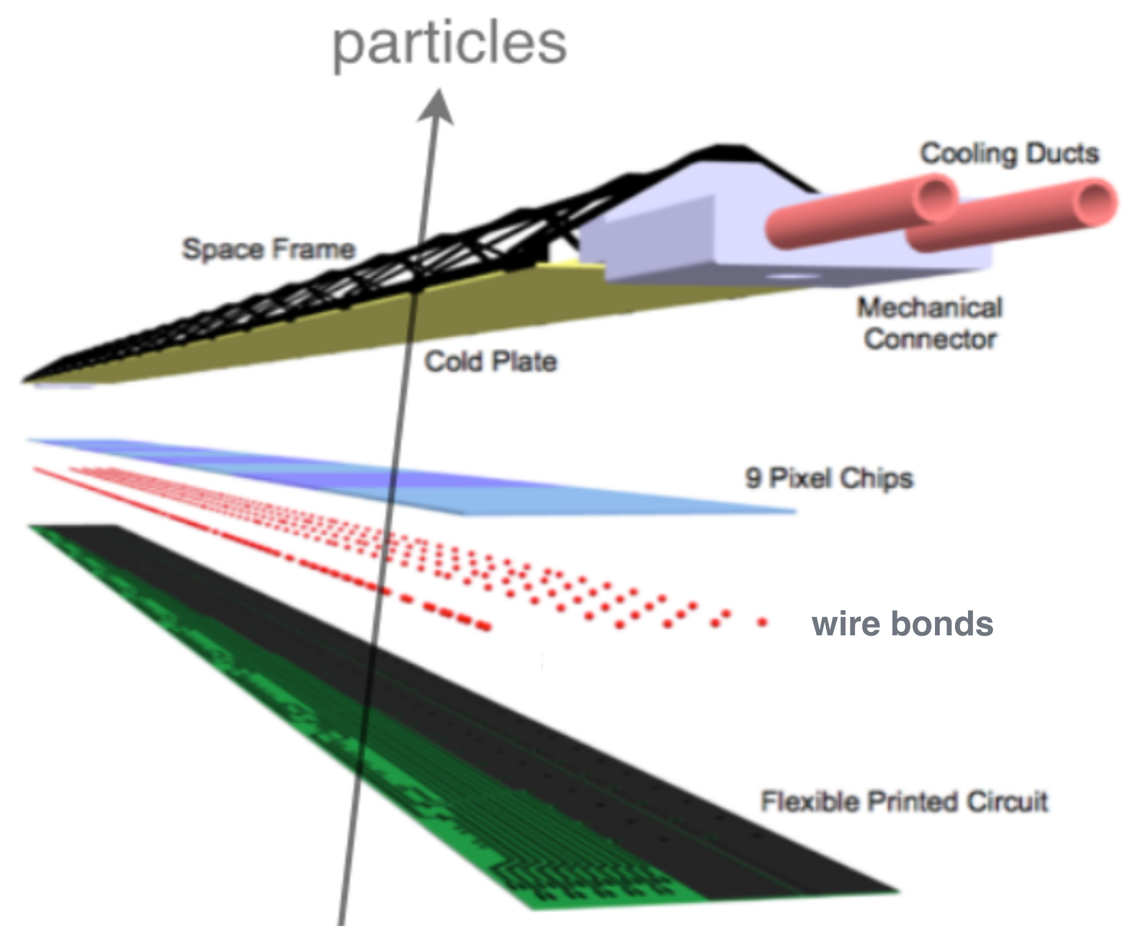
- Design: MAPS meets our requirements, additional precision
- Savings: 15+ years of ALICE R&D
- Timeliness: Extend the CERN production (2017 & 2018)
- Leverage: US institutions interested in EIC MAPS R&D

- sPHENIX Readout
  - Modified FEM-based on ALICE Readout Unit



sPHENIX MAPS Geometry I



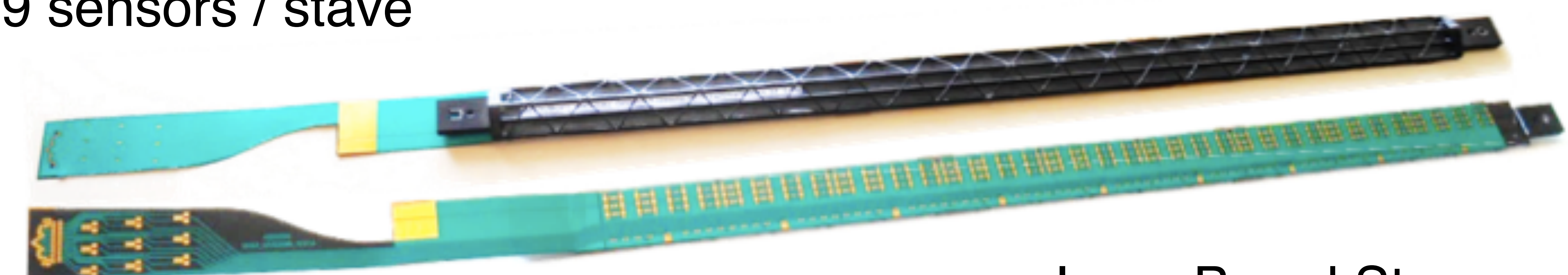


ALPIDE Generation-4 Sensor

1.5 cm x 3.0 cm x 50 um

1024*512 = 0.5M channels / sensor

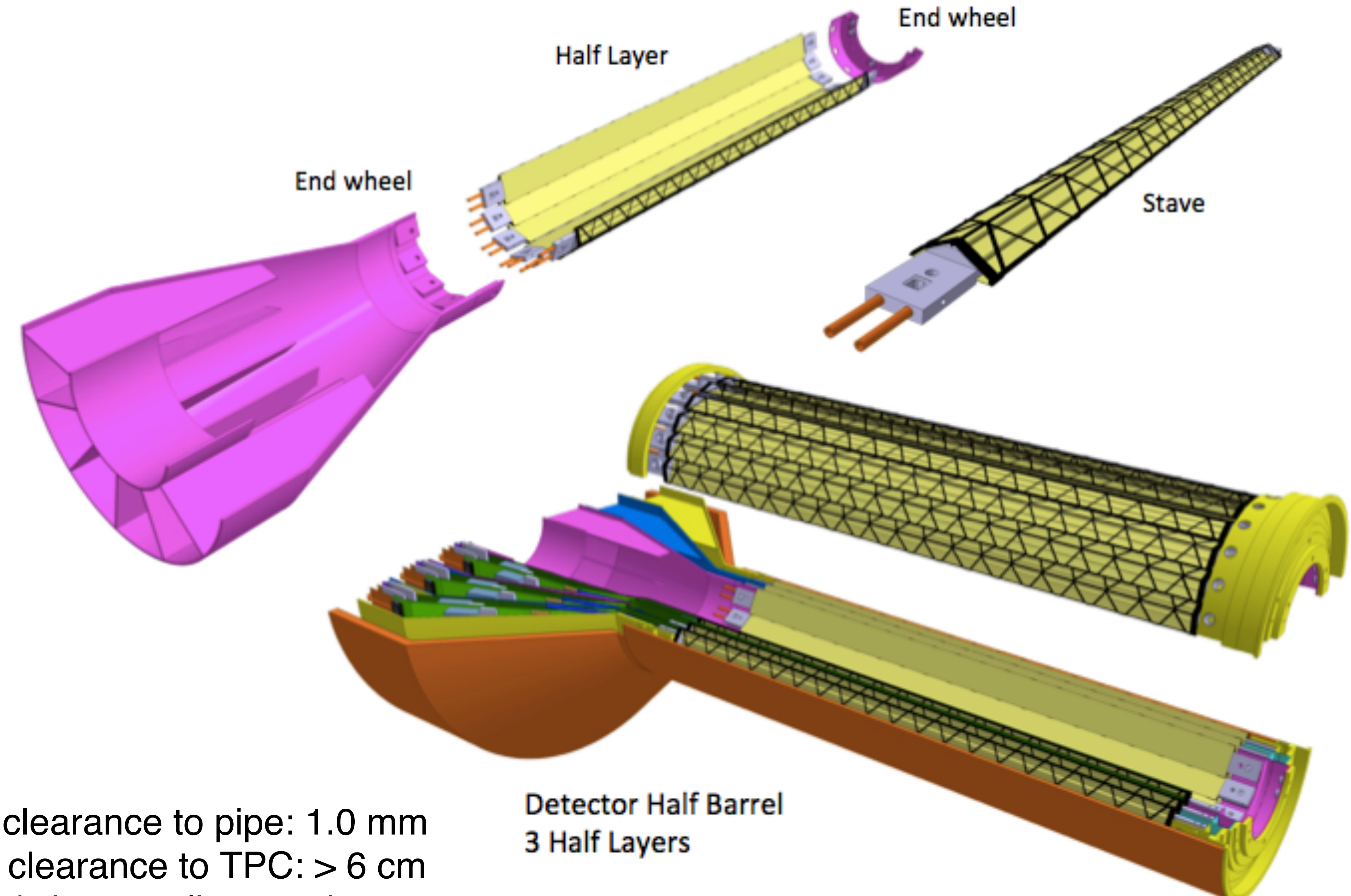
9 sensors / stave



Inner Barrel Stave

1.5 cm x 27 cm

sPHENIX MAPS Geometry II

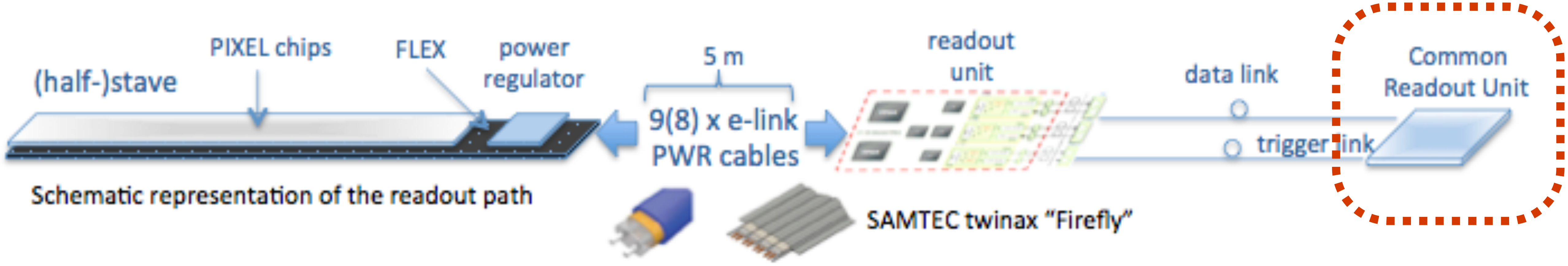


inner clearance to pipe: 1.0 mm
outer clearance to TPC: > 6 cm
* w/o intermediate tracker

MAPS Electronics

ALICE readout path

Plan A: reprogram



MAPS Electronics

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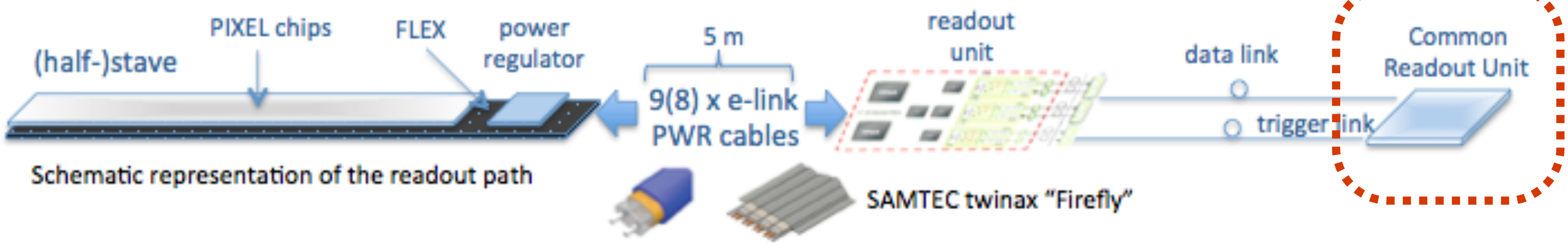
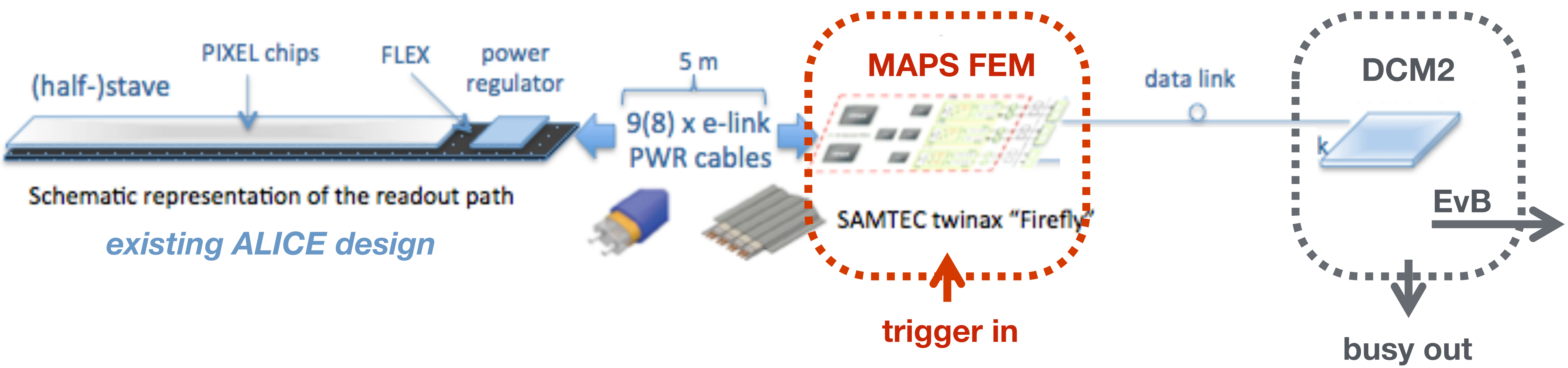


Plan B: sPHENIX readout path (held as contingency)



modified design,
starting with ALICE boards

existing sPHENIX design

LDRD Status

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX Project #20170073DR

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX

PI: Liu, Ming, X.; P-25; mliu@lanl.gov

Introduction

A few microseconds after the Big Bang, while still at a temperature of several trillion degrees, the entire universe was permeated with quark-gluon plasma (QGP). Measurements at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), where LANL plays a major role, and the Large Hadron Collider (LHC) at CERN have verified the existence of the QGP [1-4]. However, none of the existing experiments have revealed its microscopic structure, thus motivating a new experiment named sPHENIX [5]. We propose to use a combination of experimental, theoretical, and engineering expertise from LANL's P, T, AOT, and CCS Divisions to develop the next generation heavy ion physics program at LANL. We will design a new cutting-edge, low mass, high efficiency pixel-based inner tracking detector (Figure 1) needed for the sPHENIX experiment. This proposed $75M experiment will usher in a new era of fundamental discoveries in nuclear science and reveal the internal structure of the QGP near the transition temperature to conventional nuclear matter. The proposed Monolithic Active Pixel Sensor (MAPS [6]) inner tracking detector will provide an order of magnitude improvement in spatial resolution over current technologies and produce the first bottom-quark jet (b-jet) tomographic measurements of the QGP at RHIC. The data will shed new light on our understanding of b-jet interactions with the QGP medium and provide critical new information to pinpoint the transport properties of the QGP. B-jet measurements will fulfill one of the three major science pillars of sPHENIX. We will also develop the state-of-the-art theoretical and computational tools necessary to interpret and optimize the planned experimental measurements. Dr. Geesaman, chair of the DOE Nuclear Science Advisory Committee (NSAC) writes "This LDRD project will be exceptionally valuable for LANL, nuclear science and the nation."

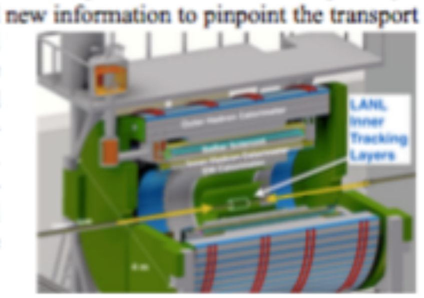


Figure 1: The sPHENIX conceptual design. Our proposed inner tracking subsystem is closest to the beam line.

Project Goals

When the fundamental constituents of matter, quarks and gluons, traverse the QGP they scatter and lose a large amount of energy before escaping, a phenomenon that is extremely useful for probing properties of the QGP [7]. The interactions of those particles with the plasma can be used to directly infer its microscopic quasiparticle structure. The final state observable is a jet, the collimated spray of particles produced by fragmentation of the scattered high-energy quark or gluon. Bottom quarks, which are ~1,000 times heavier than the light quarks, produce unique energy loss signatures due to their large mass (4.2 GeV/c^2). At momenta comparable to this scale, bottom quarks will preferentially lose energy via collisions with the plasma quasiparticles and not via gluon radiation, as is preferen-

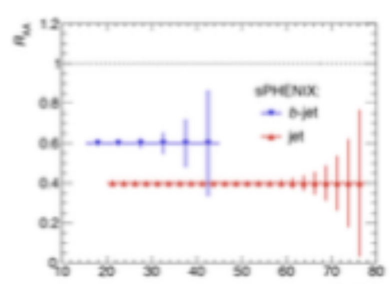


Figure 2: sPHENIX statistical projections for suppression (R_{AA}) illustrating the kinematic coverage for b-jets (blue triangles) and light jets (red triangles) [5].

Liu, Ming X. 1

Funded!

Purpose: Obtain key R&D support

Funding Profile:
$5M spread over 3 years
starting in Oct 2016

Funding Breakdown:
~1/3 M&S
~1/3 Experiment Staffing
~1/3 Theory Staffing

Proposals judged on many factors,
coverage from multiple divisions,
strong Theory is necessary to success

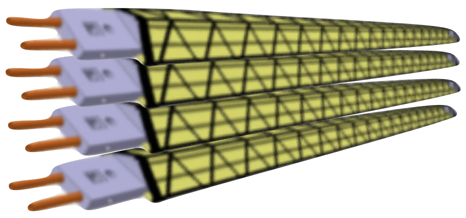
M&S total: $1.3M **Engineering: $0.5M**

MAPS Project Scope

- **Covered by MAPS project**
  - MAPS R&D effort
    - **4-stave Prototype Tracker with ALICE Readout**
    - **sPHENIX readout electronics design & prototyping**
    - **Initial Mechanics design** & prototyping & final design
    - Servicing design (safety, cooling, power, etc)
  - Construction deliverables
    - 68 staves assemblies for 3-layer IB (CERN/MIT/sPHENIX)
    - Mechanical assembly fabrication (LBNL interest)
    - Front end electronics fabrication (x68) (LANL)
    - Half-Barrel assembly, metrology (BNL)
  - Installation and Commissioning at 1008

✴ ***LDRD deliverables***

Prototype:
cosmic & beam tests



Schedule Drivers

- **sPHENIX Readout Research and Development**
  - Modified readout will begin with ALICE design
  - Multiple prototyping rounds possible
  - Full system test needed before production

- **ALICE ITS Inner Barrel Production**
  - Mid-2017: Arrival of 4-staves for R&D development
  - Mid-2018: Natural end of ALICE production
  - Late-2018: CD-3 begins

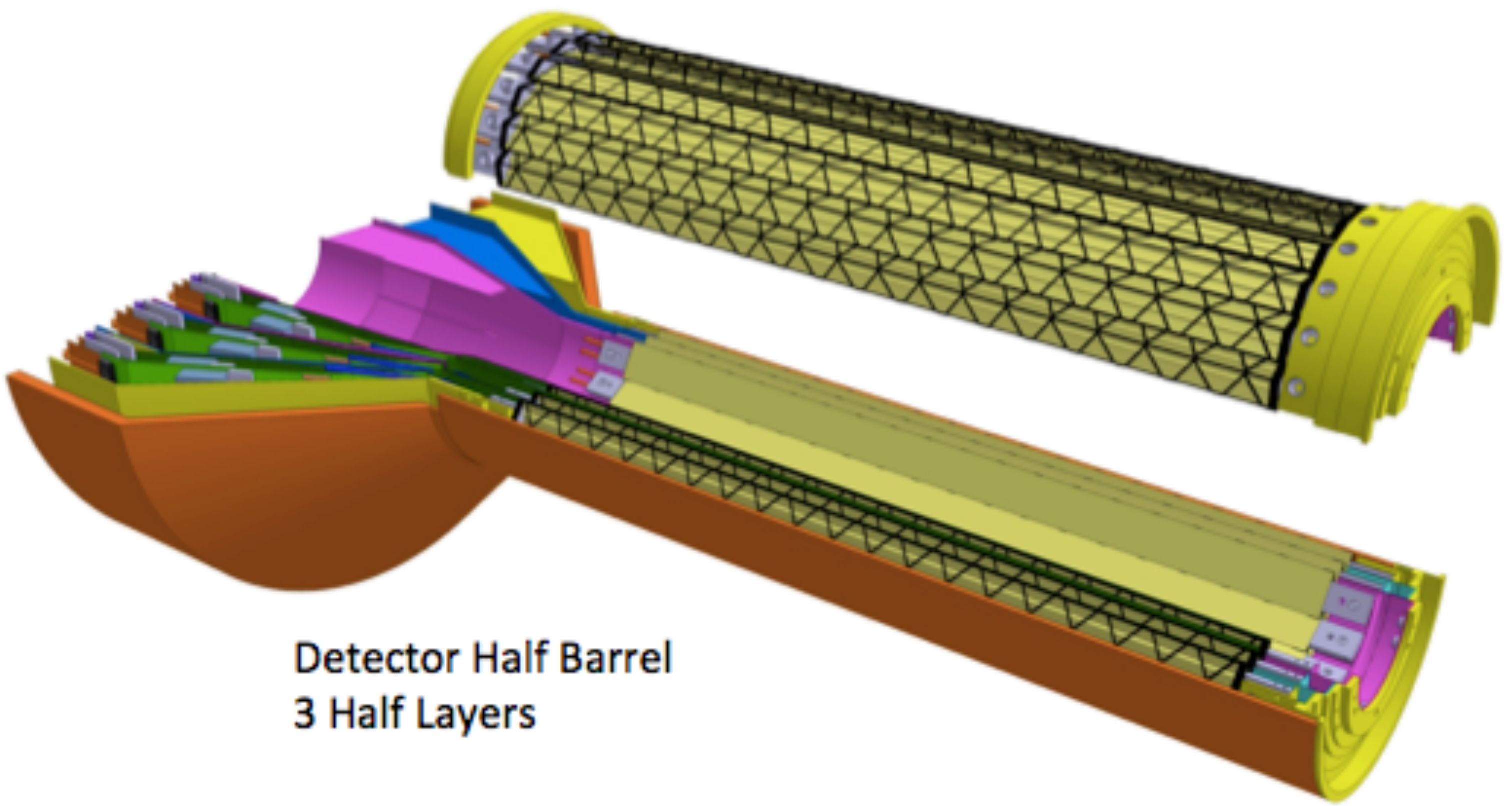
Resource/Cost Drivers

- **Building a stave assembly lab from scratch is costly and time consuming (+$1-2M cost, +1 project years)**
  - Secure access to CERN facility via MOU to extend the assembly line in Switzerland
- **Big project with many deliverables, limited LANL manpower**
  - Bring in large institutions
    - LBNL for Mechanics (discussions underway), MIT for Stave assembly
    - LANL on readout electronics (our specialty)
  - Bring in other institutions, especially to provide students, postdocs and additional expertise

Organization

Edward O'Brien
Project Director

- **John Haggerty** — *Project Manager - Science*
  - *Tracking L2 (1.3)*
    - **Ming Liu** — *MAPS L3 Manager (1.3.x)*
    - **Itaru Nakagawa** — *Strip L3 Manager (1.3.y)*
    - **Tom Hemmick** — *TPC L3 Manager (1.3.z)*
- **James Mills** — *Project Manager - Engineering*
- **Don Lynch** — *Chief Engineer*
- **Irina Sourikova** — *Project Controls*
- **Robert Ernst** — *Resource Manager*



Timeline of Major Tasks

- **Key Dates**
  - Start of LDRD funding: October 1 2016
  - Arrival of 4-staves: mid 2017
  - Full System Readout Test: late 2017
  - Readout Electronics Design Finalization: early 2018
  - **End of ALICE ITS Inner Stave assembly: mid 2018 (latest ITS update)**
  - Test Beam Operation: early 2019
  - **Ready for CD2 + CD-3 by August 2018 (sPHENIX CD-3b date)**
  - MAPS Stave Construction (9 months): late 2018 to mid 2019

Participating and Interested Institutions

- **LANL** - Readout & FEMs, Mechanics
- **MIT** - Assembly and testing, cooling
- **LBNL** – Mechanical carbon structures, readout
- **BNL** – Integration and services, safety and monitoring
- **UT-Austin** – MAPS readout electronics and testing
- **Univ. of Colorado** – sPHENIX DAQ/DCM-II integration
- **Univ. of New Mexico** – LV, cabling & connectors
- **New Mexico State University** – Tracking algorithm and simulations
- **Univ. of IL of Chicago** – Stave assembly and testing, offline analysis
- **Iowa State University** – Assembly and testing, simulations
- **Georgia State University** - Slow control and monitoring
- **Florida State University** - Offline and simulations
- **Univ. of California, Los Angeles** – Assembly and testing, simulations
- **Univ. of California, Riverside** – Assembly and testing, simulations
- **RIKEN/RBRC, Japan** – Assembly and testing, integration
- **Yonsei, Korea** – MAPS QA and readout, simulations

Issues and Concerns

(1) Mating the ALICE and sPHENIX production schedules

Challenge: now only ~1/4 year gap between completion of ALICE ITS construction and projected sPHENIX CD-2/CD-3-b.

Mitigation: train experts in-situ, maintain production line at low effort, & ramp back up, look for opportunities to close the gap.

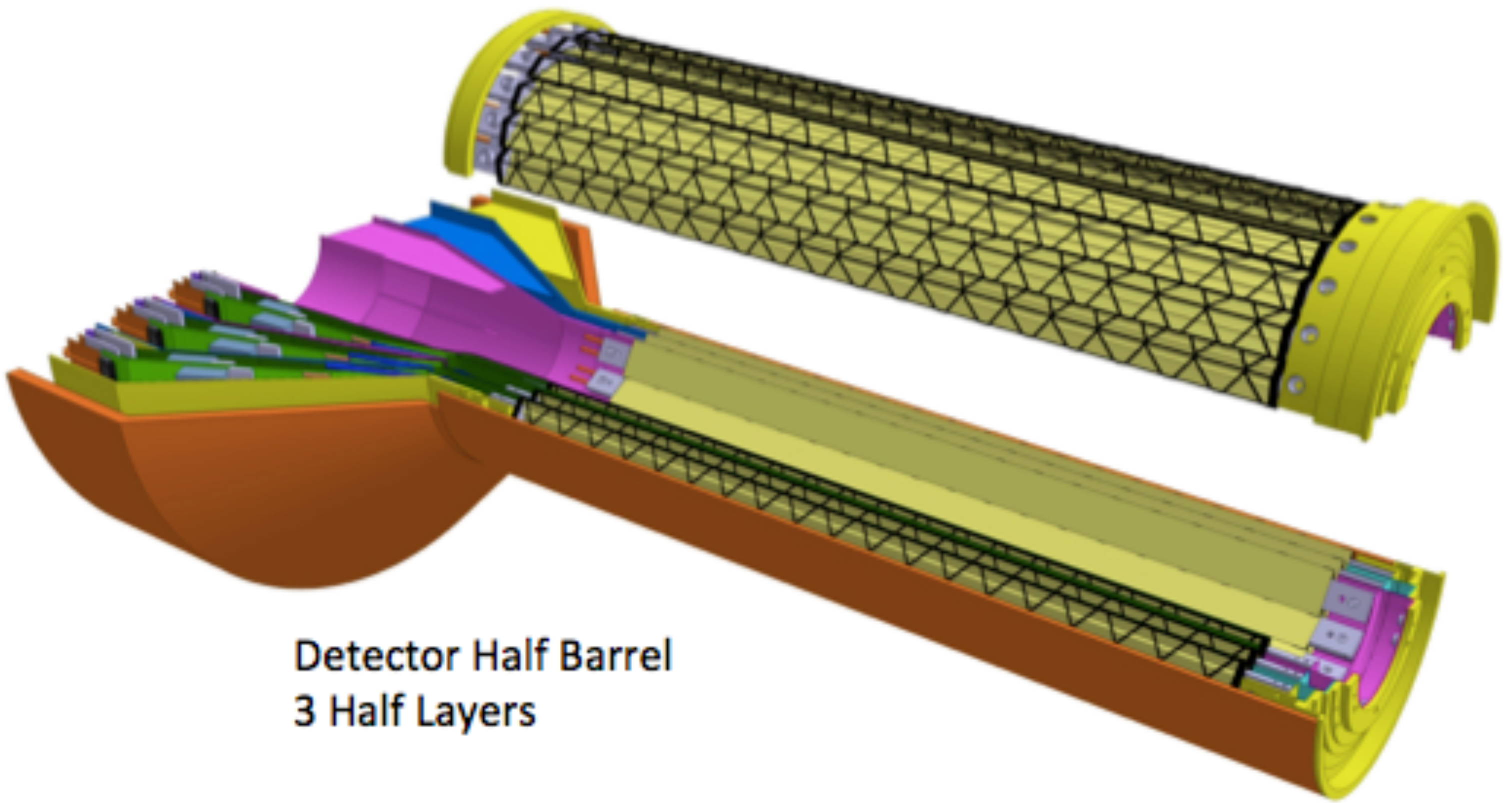
ALICE production needs to meet LHC shutdown schedule.

(2) Long Development Time for Readout Electronics

Challenge: Full custom board design may be required

Mitigation: Early review of options, early start on design work

Summary



MAPS is a conservative approach to a tough problem

Retiring the Readout risk is a top priority

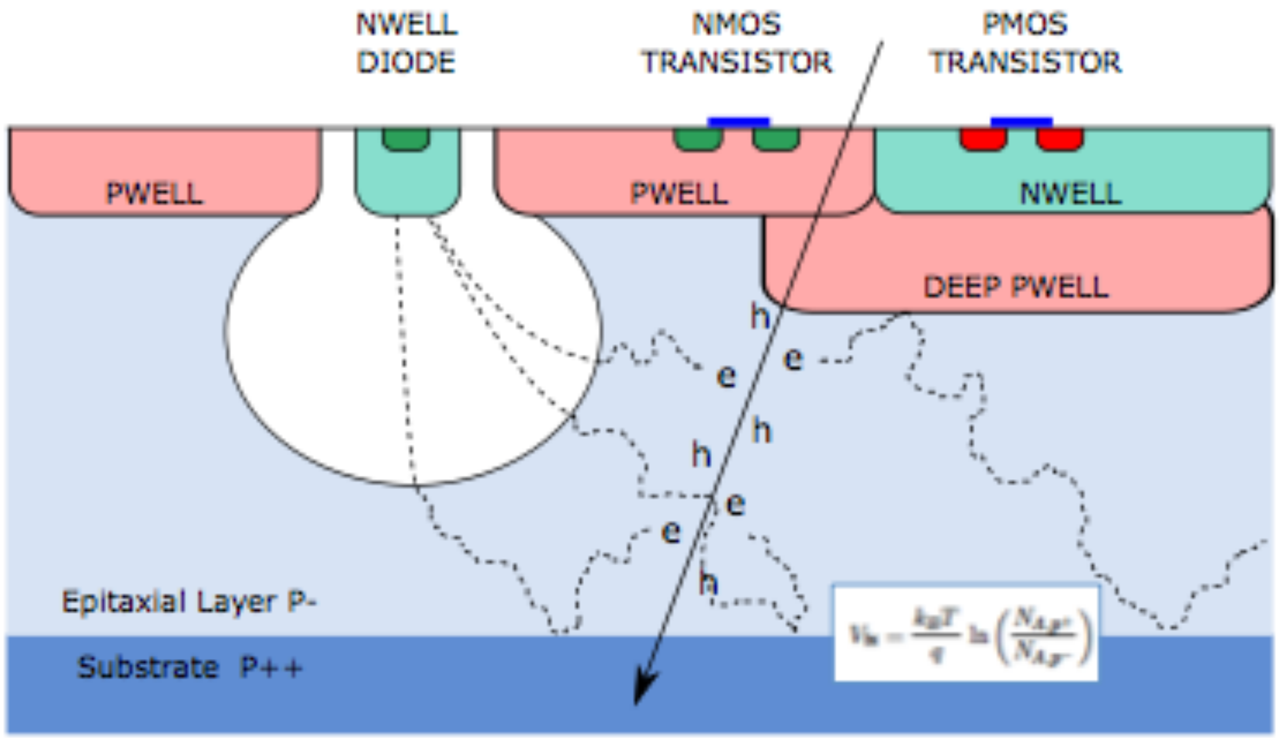
Work closely with ALICE/CERN to keep the project schedules coupled.

Actively building a collaboration on MAPS project.

Backups

ALPIDE Pixel Technology

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process



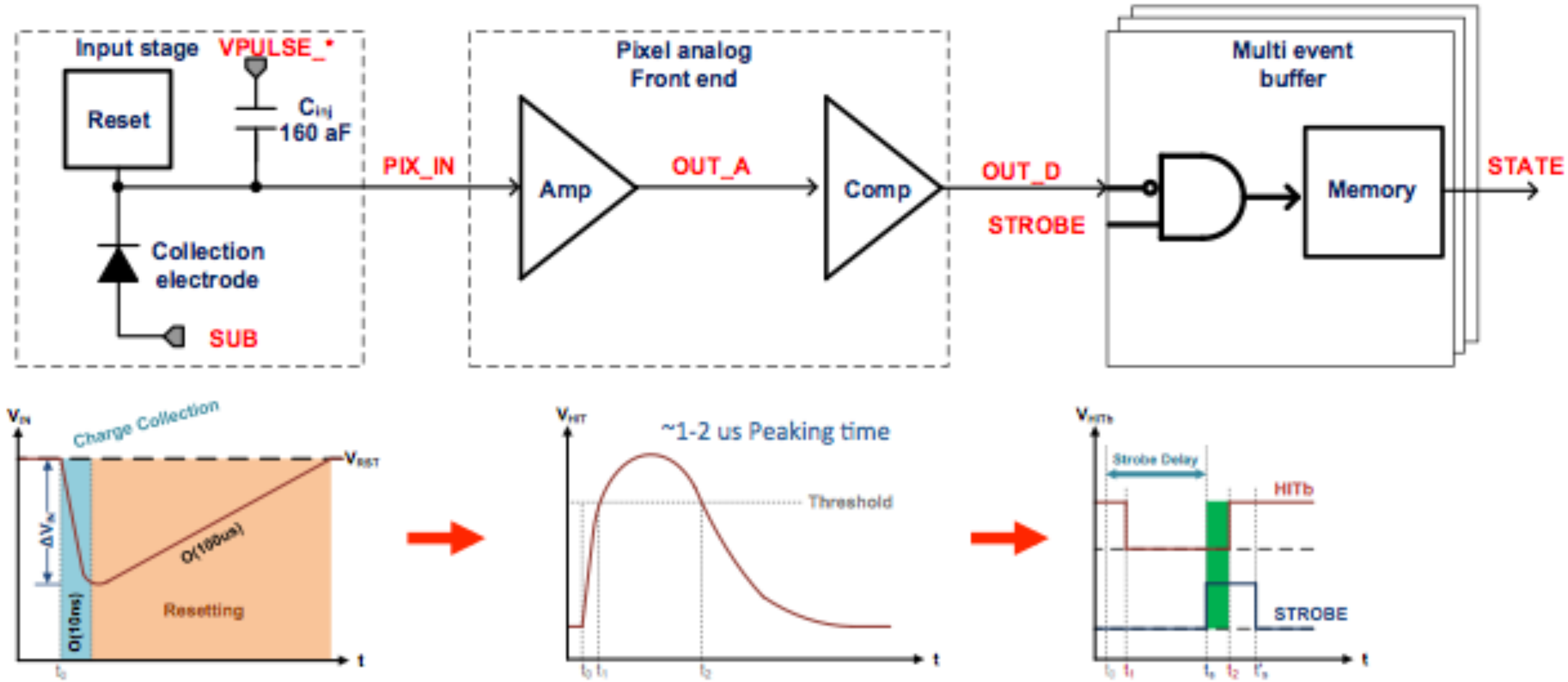
Tower Jazz 0.18 μm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18μm to 30μm) on p-type substrate
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area

ALPIDE Operation

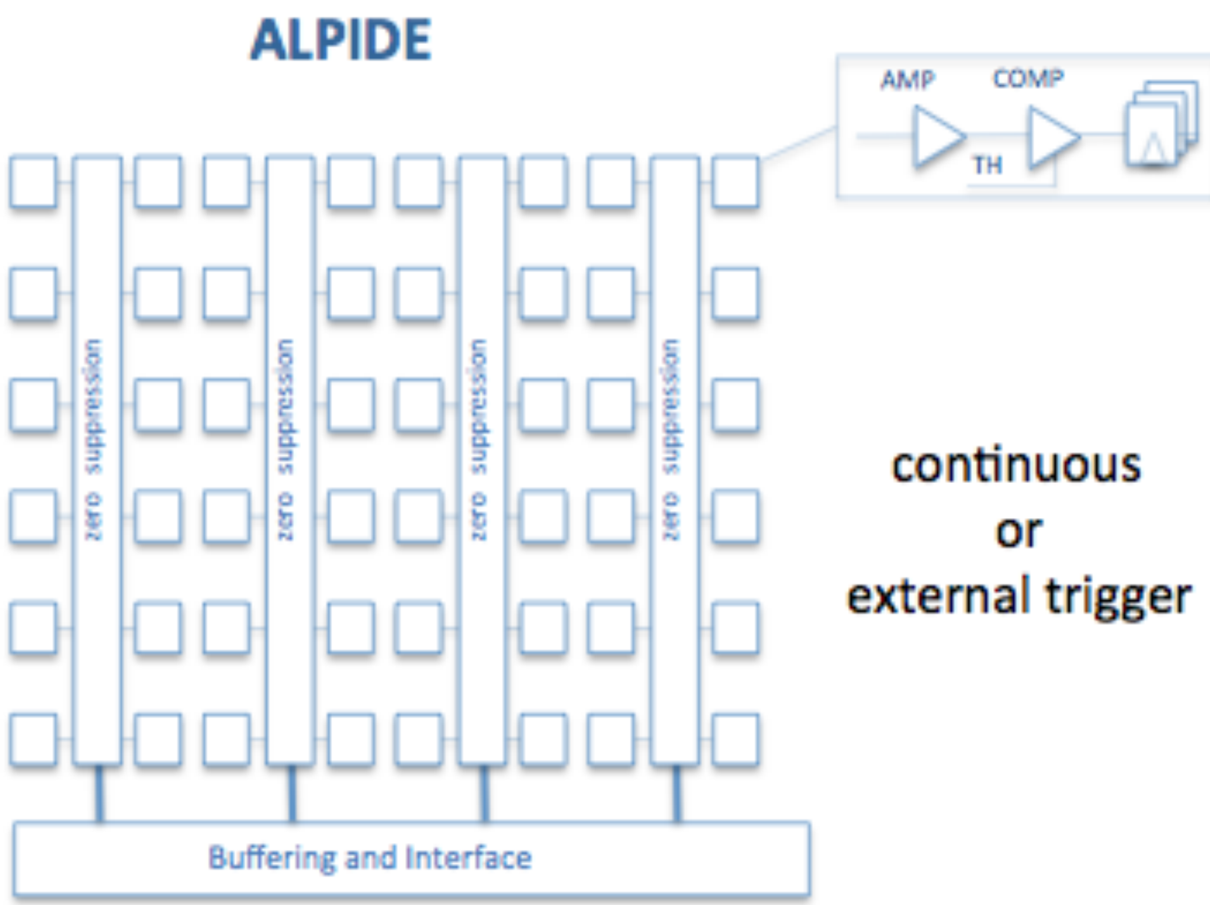


ultra low-power front-end circuit
40nW / pixel

Front-end acts as delay line

- Sensor and front-end continuously active
- Upon particle hit front-end forms a pulse with ~1-2μs peaking time
- Threshold is applied to form binary pulse
- Hit is latched into a (3-bit) memory if strobe is applied during binary pulse

ALPIDE Readout



continuous
or
external trigger

Architecture

- In-pixel amplification
- In-pixel discrimination
- In-pixel (multi-) hit buffer
- In-matrix sparsification

Key Features

- 28 μm x 28 mm pixel pitch
- Continuously active, ultra-low power front-end (40nW/pixel)
- No clock propagation to the matrix → ultra-low power matrix readout (2mW whole chip)
- Global shutter (<10μs): triggered acquisition or continuous

Design Drivers

Why not change the stave design to do *X*?

The ALICE design is well-suited for our physics and exceed our coverage needs. Potential cost savings by shortening the stave are countered by redesign costs and delays. Cooling tube design requires duplicating ALICE water cooling system

Why are three layers needed for sPHENIX?

Additional anchoring points are helpful for: secondary vertexing, pattern recognition, pileup rejection, self-alignment. Reduces need for addition tracking between MAPS and TPC. Studies of fewer layer options are still on-going.